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Electrical Power Generation from Heat Recovered at the Throat of a Downdraft Biomass Gasifier

Nzihou Jean Fidele[1, *], Hamidou Salou[2], Imbga Kossi[1], Segda Bila Gerard[3], Ouattara Frederic[1], Tiemtore Hamadou[1]

[1]Analytical Chemistry, Spatial Physics and Energetic Laboratory, Norbert Zongo University, Koudougou, Burkina Faso
[2]Catholic University of West Africa, Academic University at Bobo-Dioulasso, Bobo-Dioulasso, Burkina Faso
[3]Environnemental Physic and Chemistry Laboratory, Joseph Ki-Zerbo University, Ouagadougou, Burkina Faso

Email address:

Jean_fidele@hotmail.com (Nzihou Jean Fidele), h_salou@yahoo.fr (Hamidou Salou), kossiimbga@yahoo.fr (Imbga Kossi), gsegda@gmail.com (Segda Bila Gerard), fojals@yahoo.fr (Ouattara Frederic), ahmadtiemtore79@gmail.com (Tiemtore Hamadou)
[*]Corresponding author

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Abstract: Gasification, a thermochemical process that takes place in gasifiers, is now understood as a process of transforming the solid components of biomass into combustible gases essentially consisting of carbon monoxide (CO) and dihydrogen (H2). This technology is relatively old and was widely used during the Second World War to deal with the shortage of fossil fuels in Europe. Although gasification was abandoned in favor of oil after the Second World War, this process is experiencing a great revival of interest today for the decentralized production of energy and for covering the energy needs of the disadvantaged strata in the developing countries. We aim to experiment with small-scale gasifiers with three objectives: to produce electrical energy, to improve the energy efficiency of biomass gasifiers and to do so essentially with materials accessible on the market in developing countries at affordable costs. In this study, we successfully designed, fabricated and tested a heat recovery system from a downdraft gasifier fueled with wood chunks. The gasifier use material finds at an affordable cost. Our downdraft gasifiers have a throat which is the hottest part of the apparatus. Almost all designers insulate the throat mainly for safety, environmental protection and efficiency considerations. Instead of insulating the throat, we designed a heat recovery system surrounding the throat and generated electrical power from high pressure water vapor produced from that throat. This recovered energy is a bonus energy from a downdraft gasifier and should be added to the gasifier energy balance, thus increase the overall efficiency This led us to supplemental electrical power generation from this type of gasifiers.

Keywords: Downdraft Gasifier, Heat Recovery, Electrical Power

1. Introduction

Gasification is the processes of producing combustibles gas from solid materials such as coal, biomass or solid waste [1]. This process take place in gasifiers that can be categorized in four (04) mains designs: updraft, downdraft, crossdraft, fluidized bed [2, 3].

Each design has its own advantages and drawbacks. According to the applications of the produced gas, some designs suit best than others.

Biomass is one of the important sources of renewable energy. By 2050, biomass could provide nearly 38% of the world's direct fuel use and 17% of the world's electricity [4].

For electrical power generation, downdraft gasifiers have proved good performances compared to other designs.

Design resulting with low tar content in the produced syngas may reduce the cost of the syngas cleaning [5].

In this work, we designed, fabricated and tested a downdraft gasifier for biomass gasification. Biomass used in this work mainly consist of wood chunks. This kind of gasifier is sometimes referred to as «Imbert gasifier» (after its entrepreneurial inventor, Jacques Imbert) [6]. In our attempt to insulate the throat of our downdraft gasifier, we have end up with a new and original design that allows us to recover heat at the throat in addition to the energy supplied by an internal combustion engine from the produced combustibles gaz.

2. Materials and Methods

2.1. Biomass and Gasifier Materials

We used wood wastes (shavings and chunks) generated in the local furniture maker Workshop, for first experiments. For sake of reproducibility, the same species of wood were used all over the 3 experiments reported in this paper. The average sizes of the wood shavings were 2-5mm and wood chunks were 4-60 mm. Figure 1 depicts preparation of the wood waste used in this study.

The materials used for the fabrication of the gasifier system components were locally sourced. The materials include metal sheets, galvanized iron pipes and bars. Sealing materials include high temperatures engine gasket glue, rubber recycled from motorcycles and insulating tape. The electrical equipment includes a 12 volt, 3000-rpm blower, and 14 volts laboratory power supply. A rheostat allowed us to vary the air flow entering the primary reactor. An optimal air flow was determined in other experiments that will be described in another paper. In this work, rheostat was always set a position 6 out 10, with the optimum fund in our other experiments.

Figure 1. *Preparation of wood chunks used in this study.*

2.2. The Downdraft Gasifier and Gasification Process

Basically, gasification is a combustion reaction with the primary air supplied bellow the stochiometric ratio. Because of the incomplete combustion of the hydrocarbonated solid material, gasification produce mainly carbon monoxide (CO) and dihydrogen (H_2) that can further be oxidized in a classical combustion reaction and produce power.

Primary air is supplied to a downdraft gasifier through air nozzles. Bellow the air nozzles zone lies the gas-reduction zone, usually consisting of a classical Imbert hearth or of the V-heart. Most recently, the flat-plate heart constriction (figure 2) has been introduced. The latter two heart designs accumulate a layer of retained ash to form a high-quality, self-repairing insulation.

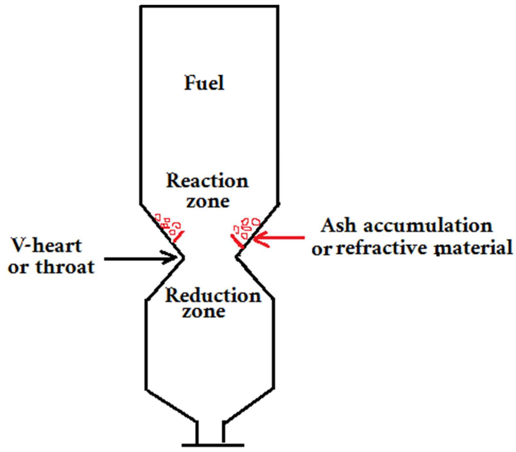

Figure 2. *A downdraft gasifier with its constricted zone.*

Be it in refractory material or a layer of retained ash, the insulation material act like a heat accumulator that regulate the temperature of the reaction zone. Thus, enhancing the efficiency of the gasification process. In fact, it has been shown that improved insulation in the throat also called hearth result in lower tar production and a higher efficiency over a wider range of operating conditions [6].

Thouht Akhator, Obanor and Sadjere [7] didn't use insulation material, they still used a constricted V-heart in their design.

2.3. Fire Hazard in a Downdraft Gasifier [6]

During a gasifier installation, one should insulate hot parts of the gasifier, install heat shields, or warning signals for workers around the hot surfaces of a gasifier. Hot metal surfaces can cause nasty skin burns at temperatures well below those that will cause the gasifier's metallic envelop to glow.

Fire hazards can result from the following causes:

1. high surface temperature of the equipment;
2. risks of sparks during refueling of the gasifier;
3. flames through gasifier air inlet on refueling lid.

Risks can be considerably decreased by taking the following precautions:

1. insulation of hot parts of the system;
2. installation of double sluice filling device;
3. installation of back-firing valve in gasifier inlet.

Considering the facts above, designers of downdrafts gasifiers often make sure to insulate the throat of their gasifier.

Mukunda [8] achieved higher efficiency of his design by allowing air distribution, increasing insulation and recirculating gas within the reactor thereby utilizing the sensible heat in the gas to dry the biomass.

A gasifier unit consist of three main parts:

1. The gasification unit
2. The purification and
3. The valorization unit.

Gasification unit mainly consist of the gasifier reactor. Our purification unit comprise a cyclone, a cooler and a filter.

We therefore designed, fabricated and tested the downdraft gasifier system shown on figure 3 below.

We also tried to insulate the throat of our gasifier with a heat insulator for car engines. But when the gasifier got hot enough to produce flammable gas, the top of our throat was glowing.

This forced us to lower the primary air blower flow and to work at lower temperatures.

As unwanted result, we were stuck to producing poorly flammable gaz.

In the midst of this puzzle, we got the idea of cooling our downdraft gasifier's heart with water. But it then appeared that the cooling water was quickly vaporized.

However, we noticed that we could then attain high air blowing rates without the glowing of our gasifier heart. Also, we noticed that produced gas was more flammable as evidenced by a blue combustion flame of the produced gas at the flaring port.

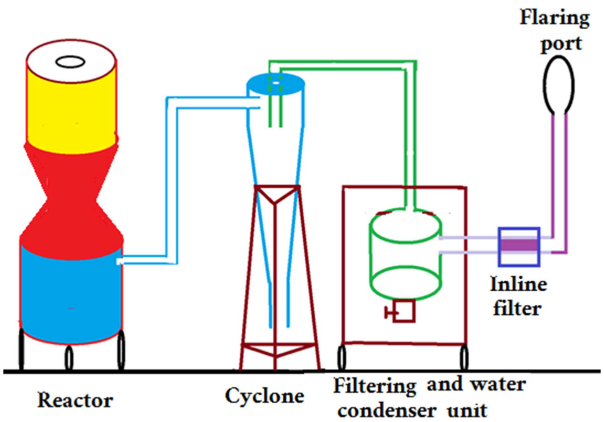

Figure 3. *Schematic of the downdraft gasifier used in this work.*

2.4. The Stream Electrical Power Generation Unit

The principle of operation of a steam turbine in a thermal power station is quite simple: the calorific energy produced at the level of the boiler (from fossil fuels for example) is transmitted to water. Its temperature increases, it vaporizes and its pressure increases considerably. This high-pressure steam is directed to the turbine where it expands. Pressure energy which is actually kinetic energy is converted into mechanical energy in the rotor blades which drives a shaft coupled to an alternator. Electrical energy is collected at the exit of the alternator thanks to the principle of the variation of the magnetic field [9, 10].

2.4.1. Principle of Operation of a Direct Current Alternator

In our work the generator studied is a 12 V solar fan motor. The alternator is a direct current generator, equipped with an inductor rotating inside a fixed armature and driven by the steam turbine by the intermediary of the reducer. The rotor or the inductor runs through a direct current supplied by the excitation system (voltage regulator) which produces in the inductor an electromagnet with a pair of poles. The rotor rotates at a speed of 3000 rpm, its rotating field creates a flux variation in the stator coils. This flow variation gives rise to an emf. induced in the coils of the alternator stator. This electrical energy is available at the output terminals of the alternator. The electromotive force is proportional both to the number of turns of the coil and to the rate of variation of the flux, therefore to the speed of rotation of the rotor. Excitation is ensured by a rotating diode exciter placed at the rear at the end of the shaft. This component consists mainly of a small inverted alternator delivering a five-phase current which, after rectification, is directed directly to the field winding of the main alternator. The electromotive force is proportional both to the number of turns of the coil and to the rate of variation of the flux, therefore to the speed of rotation of the rotor [11, 12].

2.4.2. Presentation of the Turbine

The turbo-alternator generator used in this work is composed of a recycled propeller of a turbo compressor, and an alternator rated 12V of a solar fan. The turbine is placed in a metallic box to limit pressure losses. In addition, an electrical circuit has been made to measure the voltage and the intensity as a function of the time parameter. The load used is a bicycle headlight. See figure below 4:

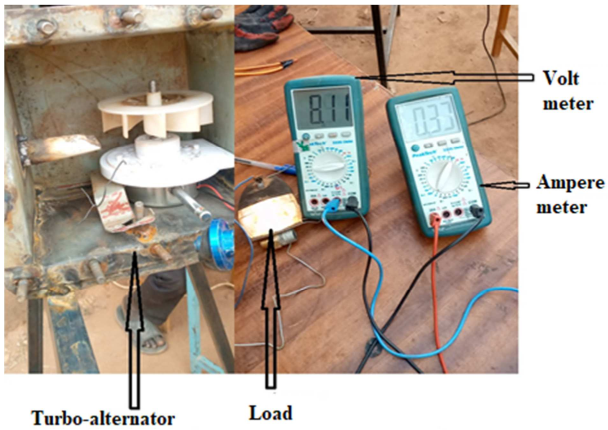

Figure 4. *Turbo-alternator; load and voltage and intensity measurement circuit.*

2.5. Methods

We then got the idea of recovering heat at the throat in order to produce water vapor and use high pressure water vapor to run a pico-turbine power generator.

From the throat shown on figure 5 (a) bellow, we welded a 2 mm thick iron sheet to make a tank that contain water. Figure 5 (b) shows the welding process and figures 6 and 7 shows the welded water tank.

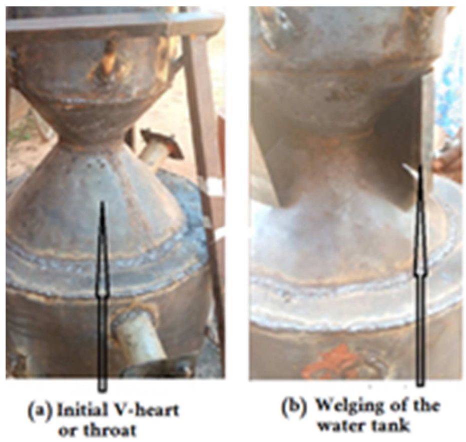

Figure 5. *Installation of the water vapor generator tank.*

Figure 6. *Welding of the water tank around the V-heart.*

After we placed flexible pipes and finished, we then got the following downdraft gasifier shown in figure 7:

Figure 7. *Downdraft gasifier with the water vapor generation circuit.*

That heat recovery system and electrical power generation system can be depicted with a schematic as shown in figure 8 below:

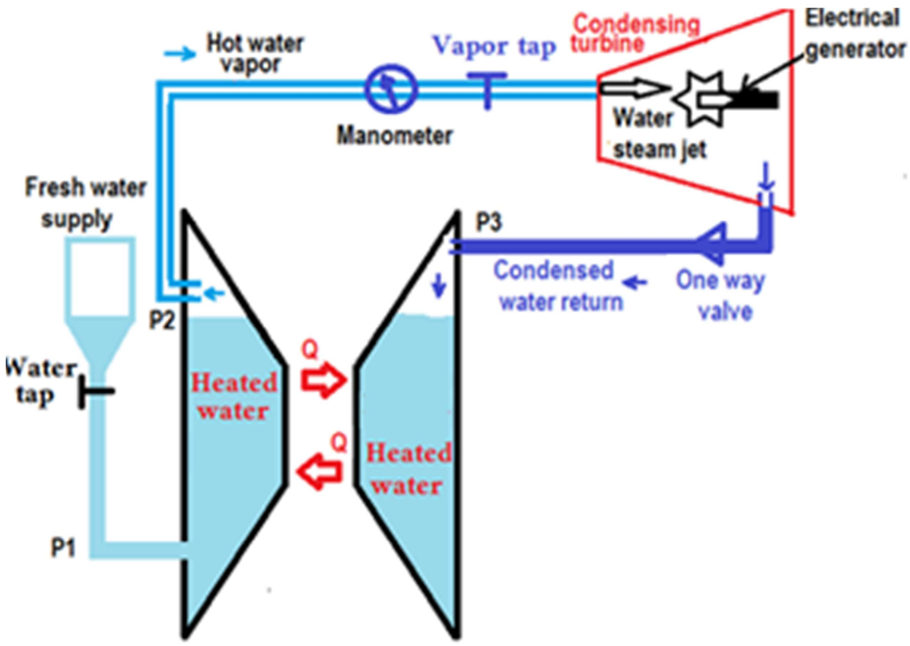

Figure 8. *Schematic of the pico-turbine electrical power generation system.*

3. Results

Through our bibliographic studies, we have developed an experimental protocol for the different measures. The objective of this protocol is to carry out the measurements in the best conditions to obtain reliable results and the safety of people and equipment. As part of such a study, the impact of operating parameters on engine performance is analyzed in order to establish the correlations that may exist between these parameters and the operation of the generating set. The steps taken into account in our work are as follows:

1. Make the complete circuit diagram;
2. Choose the different components of the assembly and arrange them, respecting for each the arrangement indicated by the assembly;
3. The rules to be respected such as the functions, gauges of the measuring devices.
4. Ensures that all devices are in off positions;
5. Check that the power supply voltage is set to zero;
6. The cables used must be compatible with the intensity involved to avoid damaging the various components;
7. Have the supervisors follow the edits before powering up;
8. The nature and characteristics of the biomass used in the gasifier such as the chemical composition, humidity, tar and particle levels of the gas produced by the gasifier. In addition to this we have the temperature of the gases during operation and the climatic hazards and the periods of the experiments to know when the

experiments were carried out.

We carried out several tests with the steam turbine, among which we selected three (03) measurement sets to illustrate the work reported here. T denotes the instant of measurement, U the measured voltage, I the intensity and P the electrical power respectively.

Table 1. *Measurement set number 1 of 12 December 2022.*

T (min)	1	2	3	4	5	6	7	8	9	10
U (V)	7.79	5.65	5.33	3.32	5.87	6.12	4.68	4.15	5.04	4.69
I (A)	0.31	0.24	0.25	0.18	0.39	0.4	0.35	0.25	0.27	0.3
P (W)	2.41	1.36	1.33	0.60	2.29	2.45	1.64	1.04	1.36	1.41

T (min)	11	12	13	14	15	16	17	18	19	00
U (V)	4.39	3.91	6.18	6.62	4.92	8.11	9.86	9.96	8.54	9.16
I (A)	0.27	0.23	0.36	0.39	0.25	0.33	0.3	0.3	0.35	0.36
P (W)	1.19	0.90	2.22	2.58	1.23	2.68	2.96	2.99	2.99	3.30

T (min)	21	22	23	24	25	26	27	28	29	30
U (V)	8.67	6.95	7.44	7.02	6.2	5.22	4.3	6.32	7.09	6.72
I (A)	0.36	0.32	0.32	0.32	0.29	0.2	0.24	0.3	0.31	0.31
P (W)	3.12	2.22	2.38	2.25	1.80	1.04	1.03	1.90	2.20	2.08

T (min)	31	32	33	34	35	36	37	38	39	40
U (V)	6.68	6.61	6.47	5.51	4.47	4.75	3.94	7.91	7.35	7.18
I (A)	0.3	0.31	0.29	0.27	0.24	0.26	0.22	0.33	0.32	0.31
P (W)	2.00	2.05	1.88	1.49	1.07	1.24	0.87	2.61	2.35	2.23

T (min)	41	42	43	44	45	46	47	48	49	50
U (V)	6.23	5.89	5.89	5.42	6.77	10.84	10.63	9.04	9.22	6.93
I (A)	0.28	0.28	0.26	0.27	0.3	0.4	0.39	0.36	0.37	0.31
P (W)	1.74	1.65	1.53	1.46	2.03	4.34	4.15	3.25	3.41	2.15

T (min)	51	52	53	54	55	56
U (V)	6.92	6.35	5.8	4.67	4.34	3.23
I (A)	0.31	0.29	0.27	0.24	0.23	0.19
P (W)	2.15	1.84	1.57	1.12	1.00	0.61

This allowed us to plot curves shown on figure 9 below:

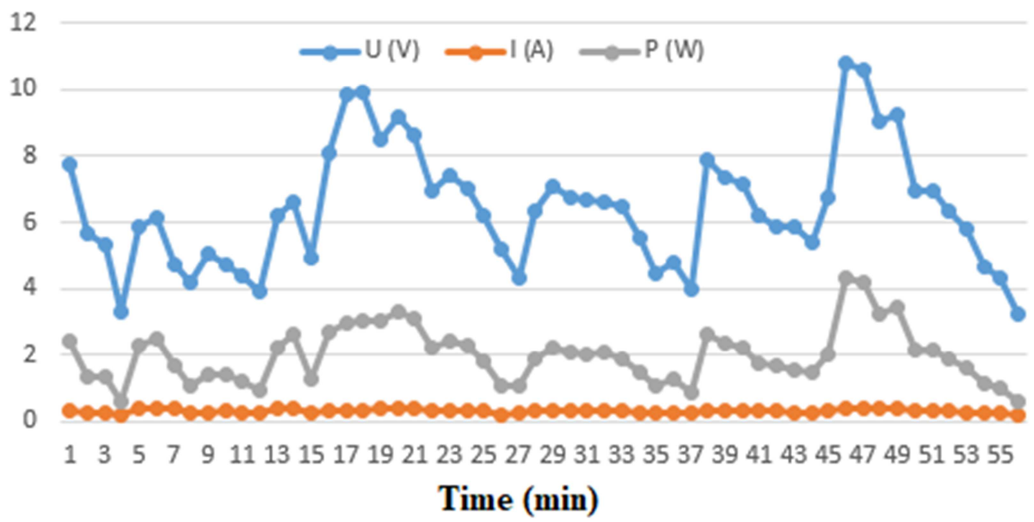

Figure 9. *Curves plotted from table 1.*

Table 2. *Measurement set number 2.*

T (min)	2	4	6	8	10	12	14	16	18	20
U (V)	10.4	10.4	9.73	8.6	7.03	6.77	5.14	6.33	5.98	5.49
I (A)	0.39	0.38	0.36	0.36	0.3	0.29	0.26	0.29	0.28	0.26
P (W)	4.05	3.93	3.50	3.10	2.11	1.96	1.34	1.84	1.67	1.43

Table 2. *Continued.*

T (min)	22	24	26	28	30	32	34	36	38	40
U (V)	5.42	5.18	5.04	5.26	4.90	4.67	3.33	3.59	2.5	1.87
I (A)	0.25	0.23	0.24	0.25	0.24	0.23	0.19	0.19	0.15	0.11
P (W)	1.36	1.19	1.21	1.32	1.18	1.07	0.633	0.682	0.375	0.206

Table 3. *Measurement set number 3.*

T (min)	2	4	6	8	10	12	14	16	18	20
U (V)	10.4	10.4	9.73	8.6	7.03	6.77	5.14	6.33	5.98	5.49
I (A)	0.39	0.38	0.36	0.36	0.3	0.29	0.26	0.29	0.28	0.26
P (W)	4.05	3.93	3.50	3.10	2.11	1.96	1.34	1.84	1.67	1.43

Table 3. *Continued.*

T (min)	22	24	26	28	30	32	34	36	38	40
U (V)	5.42	5.18	5.04	5.26	4.9	4.67	3.33	3.59	2.5	1.87
I (A)	0.25	0.23	0.24	0.25	0.24	0.23	0.19	0.19	0.15	0.11
P (W)	1.36	1.19	1.21	1.32	1.18	1.07	0.63	0.68	0.38	0.21

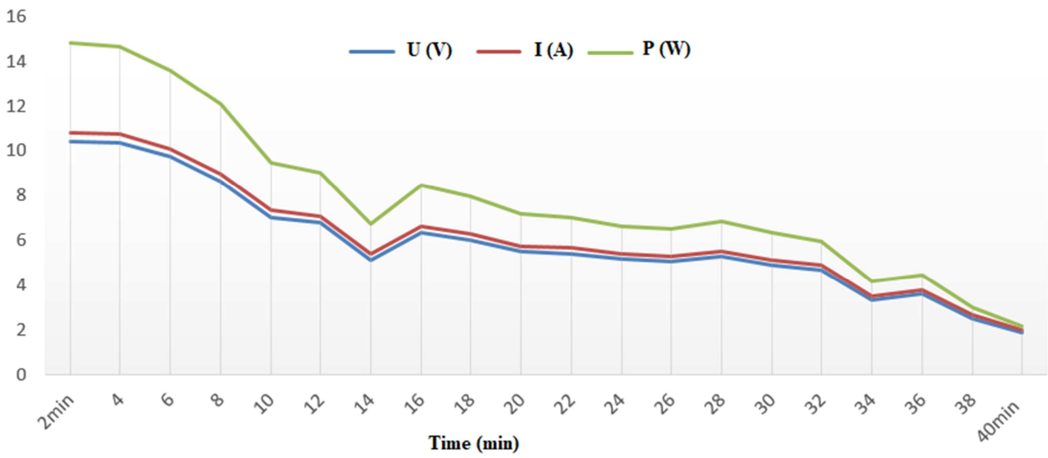

Figure 10. *Curves plotted from table 2.*

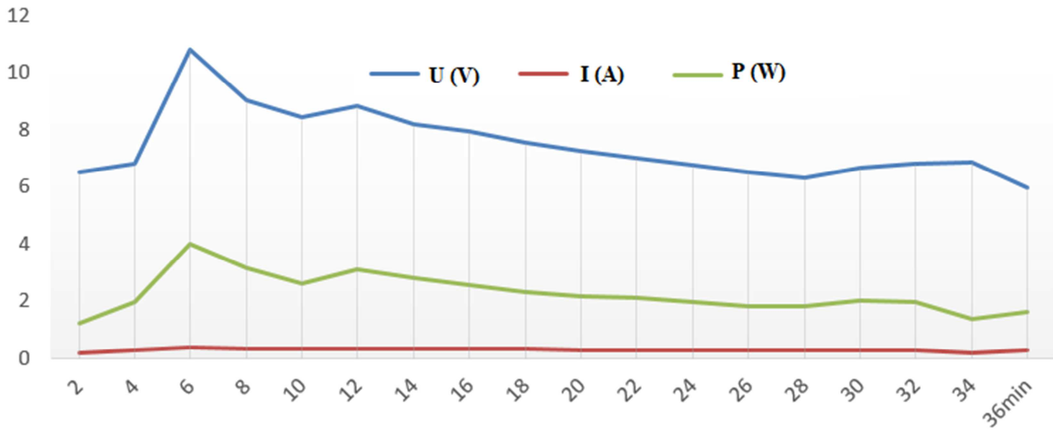

Figure 11. *Curves plotted from table 3.*

4. Discussion

From the above results and those obtained from other sets of experiments, we observe different maximum and minimum peaks of the Voltage and the Intensity. This is due to the decrease of the quantity of water in the heat recovery tank.

In fact, the amount of water put in the heat recovery tank is 5L. It heats up depending on the time and the volume flow of the primary air blower of the gasifier's reactor. The heated water vaporizes at 100°C and high pressure because of accumulation of water vapor in the heat recovery tank that is initially closed. We regulate the water vapor admission in the turbine with a one-way valve. Once we have enough hot vapor pressure, we open the valve and the hot water vapor steam flow into the turbine. This turbine rotates the fins of a 12V rated solar ventilator. This result in electrical power generation. Voltage (V) and intensity (I) are measured with two (02) multi-meters. Because water level decrease in the hat recovery tank, pressure drops are observed, which correspond to low voltage and low intensity evidenced on figures 9, 10 and 11.

A 12V and 1A rated lamp was used as a load.

The work carried out herein aimed an experimental study of a pico electrical power generator from heat recovered at the throat of a downdraft gasifier.

This recovered energy is a bonus energy from a downdraft gasifier and should be added to the gasifier energy balance, thus increase the overall efficiency [13, 14].

Water tank have 5L capacity. Minimums denotes pressure drop inside the water tank and water refill during the operation.

First of all, we carried out a bibliographic review on gasification and its applications in various fields. We chose a pico electrical power generator to allow us make various testing in several experimental conditions at an affordable cost.

The production of energy from biomasses on micro-scale can be made from different perspectives: from the obtainment of producer gas from a gasifier to the cleaning of it removing tar in a scrubber filled with vegetable oils, to the use of producer gas in engine and Solid Oxide Fuel Cell (SOFC) [15]. We achieved experimental producer gas production from this rudimentary gasifier.

As for Chawdhurya and Mahkamovb [16] our downdraft biomass gasifier was developed mainly for testing purpose. A number of technical and operational limitations are to be pointed out:

a) The gasifier was not built for continuous operation. At each refueling, the top cover needed to be opened and this caused a lot of air leakage and heat loss.
b) The design did not include any special fuel feeding hopper. Instead, a simple small fuel feeding hole was used. Feeding of biomass was tough and time consuming.
c) Thought we have provisioned an ignition port to initiate the combustion in the oxidation zone, it needs to be enhanced for easer startup.
d) Heat recovery circuit isn't fully automated, because 3 of our one-way valves were destroyed due to excessive inside pressure.

5. Conclusion

In this work, we successfully designed, fabricated and tested a heat recovery system from a downdraft gasifier fueled with wood chunks.

The gasifier has been designed and fabricated with easy to find material and at an affordable cost.

Heat produced haven't fully used to produce electrical power. The rudimentary turbo-alternator used here is solely for the proof of concept. Industrial made pico-turbo alternator should be used in upcoming work to best use the produced steam.

Water recovery from the V-heart showed beneficial to the operation of our gasifier. A part from allowing higher primary blowing rate without glowing at the throat, this resulted in a better produced syngas quality.

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References

[1] Arthur M. James R., Wenqiao Yuan, Michael D. Boyette, Donghai Wang Airflow and insulation effects on simultaneous syngas and biochar production in a top-lit updraft biomass gasifier, 2017.

[2] T. B Reed and A Das, Handbook of Biomass Downdraft Gasifier Engine Systems, Solar Energy Research Institute p. 33, 1950. https://www.nrel.gov/docs/legosti/old/3022.pdf, accessed 06 january 2023.

[3] Hasan, J., Keshwani, D. R., Carter, S. F., Treasure, T. H., 2010. Thermochemical Conversion of Biomass to Power and Fuels. In Cheng J. (Ed.), Biomass to Renewable Energy Processes. CRC Press, Boca Raton, pp. 437-489.

[4] A. Demirbas, "Combustion characteristics of different biomass fuels," Progress in Energy and Combustion Science, vol. 30, no. 2, pp. 219–230, 2004.

[5] T. A. Milne, N. Abatzoglou, R. J. Evans, *Biomass Gasifier "Tars": Their Nature, Formation, and conversion*. NREL/TP-570- 255357 National Renewable Energy Laboratory Colorado, USA November 1998.

[6] T. B Reed and A Das, Handbook of Biomass Downdraft Gasifier Engine Systems, Solar Energy Research Institute, p. 122, 1950. https://www.nrel.gov/docs/legosti/old/3022.pdf, accessed 06 January 2023.

[7] P. E. Akhator, A. I. Obanor and E. G. Sadjere, Design and development of a small-scale biomass downdraft gasifier, Nigerian Journal of Technology (NIJOTECH) Vol. 38, No. 4, October 2019, pp. 922–930 Print ISSN: 0331-8443, Electronic ISSN: 2467-8821 http://dx.doi.org/10.4314/njt.v38i4.15

[8] H. S. Mukunda, S. Dasappa, P. J. Paul, N. K. S. Rajan, and U. Shrinivasa, "Gasifiers and combustors for biomass - technology and field studies," Energy for Sustainable Development, vol. 1, no. 3, pp. 27-38, 1994.

[9] Alexandre LALEYE et Cheick O. SANOU, «Modélisation et régulation d'une turbine à vapeur dans une centrale thermique», d'ingénieur de conception, UNIVERSITE CHEIKH ANTA DIOP, 128p, 2005.

[10] MAZIGHI SIDALI ET HOCINE MOHAMED, «Etude et Simulation des défauts d'excitation d'un groupe turbine-alternateur 32 MVA», mémoire de master, Université SAAD DAHLAB de BLIDA, (2018), P21-22.

[11] François J., Abdelouahed L., Mauviel G., Feidt M., Rogaume C., Mirgaux O., Patisson F. and Dufour A., (2012), Estimation of the energy efficiency of a wood gasification CHP plant using Aspen Plus, Chemical Engineering Transactions, 29, 769-774.

[12] Le Minh Nhut, Young-Sub Moon, Youn Cheol Park. A Study on Energy Optimization of Heat Exchangers in a Gasification System. International Journal of Mechanical Engineering and Applications. Vol. 4, No. 3, 2016, pp. 123-129. doi: 10.11648/j.ijmea.20160403.14.

[13] Henriksen, U. B., Ahrenfeldt, J., Jensen, T. K., Gøbel, B., Bentzen, J. D., Hindsgaul, C., & Sørensen, L. H. (2003). The Design, Construction and Operation of a 75 kW Two-Stage Gasifier. In The 16. International Conference of Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems, ECOS 2003 (pp. 1081-1088). Technical University of Denmark.

[14] Abubakar A. Bukar, M. Ben Oumarou2, Babagana M. Tela, Abubakar M. Eljummah Assessment of Biomass Gasification: A Review of Basic Design Considerations American Journal of Energy Research, 2019, Vol. 7, No. 1, 1-14.

[15] Moriconia N., Larancia P., D'Amicoa M., Bartocci P., D'Alessandroa B., Cintib G., Baldinellib A., Discepolib G., Bidinic G., Desideric U., Cotanaa F. and Fantozzic F. Design and Preliminary Operation of a Gasification Plant for Micro-CHP with Internal Combustion Engine and SOFC. ELSEVIER, 69th Conference of the Italian Thermal Engineering Association. Energy Procedia 81, Pp. 298-308, 2014.

[16] M. A. Chawdhurya and K. Mahkamovb. Development of a Small Downdraft Biomass Gasifier for Developing Countries. JOURNAL OF SCIENTIFIC RESEARCH J. Sci. Res. 3 (1), 51-64 (2011) www.banglajol.info/index.php/JSR